Quantitative Chemical Mass Transfer in Coastal Sediments During Early Diagenesis: Effects of Biological Transport, Mineralogy, and Fabric

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Thrust Category: Sediment Processes

LONG-TERM GOALS

The objectives of this study are: to measure rates and depths over which macroinvertebrates in selected functional groups transport sediment and create sedimentary structure; and, to derive quantitative mechanistic models for these property distributions.

OBJECTIVES

Benthic invertebrates of selected species will be collected from nearshore waters, placed in mesocosms containing prepared natural sediments, and time-series observations of sediment properties will be acquired over periods up to 12 months. The goal is to evaluate spatial and temporal particle mixing and evolution of sedimentary fabric in natural sediments under controlled conditions, using minimally invasive methods. Laboratory observations will be validated by measurement of comparable parameters (e.g., bioturbation rate, depth) in the field. Results of this work will be incorporated into diagenetic mass-transport models that are being developed by Yoko Furukawa (NRL-SSC) and Carla Koretsky (W. Michigan U.)

APPROACH

Selected field sites will be sampled quarterly for the duration of the project. The following analyses are being performed for quarterly cruises: Benthic macrofaunal distribution; activities of excess ^{234}Th (source: U-series, $t_{1/2}$ = 24 days, 63 KeV peak), ^{7}Be (source: cosmogenic, $t_{1/2}$ = 52 days, 477 KeV peak), excess ^{210}Pb (source: U-series, $t_{1/2}$ = 22 years, 46.5 KeV peak), and ^{137}Cs (source: nuclear fallout and reactors, $t_{1/2}$ = 31 years, 661.6 KeV peak); sediment porosity; and sedimentary fabric (replicate X-radiographs of box-core samples, and petrographic thin sections for selected features).

Mesocosms consist of glass aquaria (75-liter to 210-liter capacity), containing 15-20 cm of muddy sediment collected from the field sites. To evaluate time-dependent effects of bioturbation, three quadrants of a mesocosm will be populated with one species at field densities, with the fourth quadrant as an unpopulated control. Populated quadrants will be sampled at 1, 2, and 4 months after organism introduction. The control will be sampled with the final quadrant. To evaluate density-dependent effects in a separate mesocosm, three quadrants will be populated at densities of ~0.1x, ~0.5x, and ~2x field densities of organisms. Resistivity profiles will be collected using a miniature Wenner-type probe to allow estimates of porosity using the Archie relationship. Bioturbation rate and depth will be assessed using a combination of tracer studies and direct measurements. Sediment processed for mesocosm use will be spiked with ^{134}Cs to an activity of ~100 dpm/g, and added to unlabeled mesocosm substrate as discrete layers, prior to organism introduction. ^{134}Cs activity will be measured by γ-spectroscopy. Non-labeled sediment will be measured for background ^{134}Cs activity. For organisms that produce fecal mounds or pellets, fecal material will be collected and weighed to determine particle mass-egestion rates. X-radiographs and CT scans from NRL-SSC and LSU-CSI mesocosms will be analyzed for time-series measurement of burrow volume and depth-dependence.

Benthic microcosms will be constructed for measurement of burrow geometry and volumetric bioturbation rates. Organisms will be introduced into microcosms at variable densities in order to evaluate density-dependent feeding and burrowing. X-radiographs (2D) and CT scans (3D) of microcosms will be obtained at monthly intervals for burrow characterization. X-radiographs will be digitized, and data will be analyzed for burrow volume and geometry. Bioturbation rate and depth will be assessed using ^{134}Cs as a deliberate tracer. A layer of ^{134}Cs-spiked sediment will be placed on the sediment surface, and 5-10 cm below the sediment surface of microcosms, and vertical mixing of ^{134}Cs will be monitored using a NaI-γ detector system.

Results from radionuclide analyses and particle-mixing experiments will be analyzed using a suite of steady-state and time-dependent advection-diffusion-reaction models for bioturbation (and sedimentation, where appropriate) (e.g., Boudreau, 1986, Boudreau and Imboden, 1987, Rice, 1986, and Soeteart et al., 1996).

WORK COMPLETED

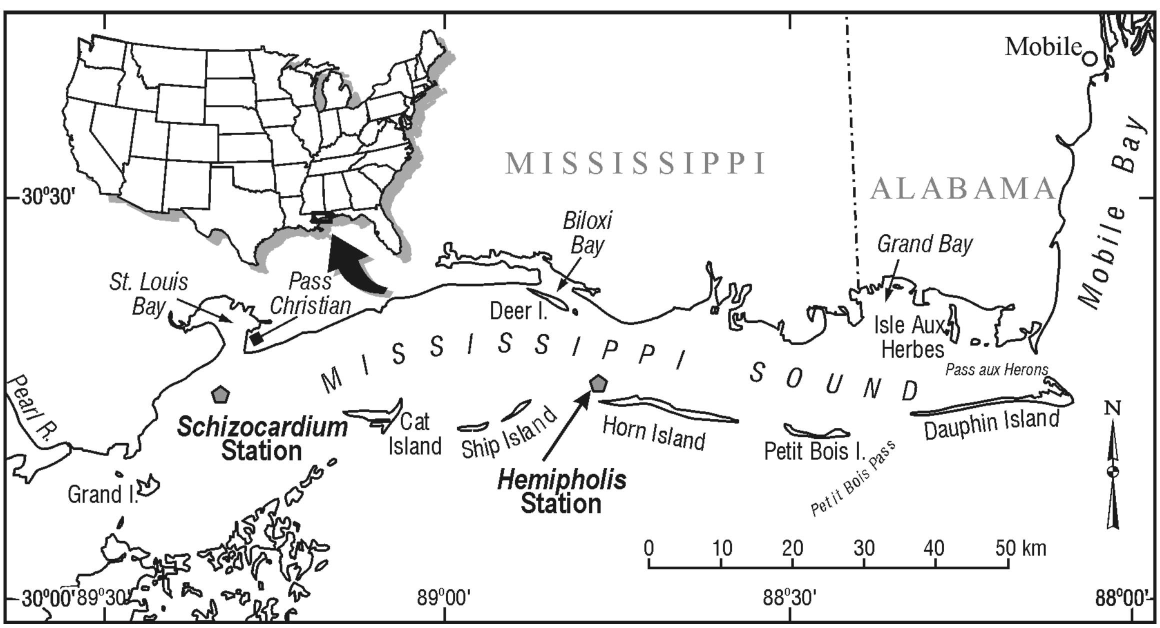

Figure 1. Location map for Schizocardium and Hemipholis stations, Mississippi Sound. Water depth and salinity are ~3 m, ~20 psu, and ~ 5 m, 27 psu, respectively, for the Schizocardium and Hemipholis stations.

In western and eastern Mississippi Sound, dense populations of a funnel-feeding enteropneust (*Schizocardium* sp.) and a surface-deposit feeding brittlestar (*Hemipholis elongata*) have been identified for detailed study (Figs. 1 and 2). Preliminary cruises have been undertaken with NRL collaborators to delineate organism distributions and associated seabed properties. For both sampling locations, replicate cores have been subsampled for benthic-community analysis, X-radiography, particle-bound radionuclides (^{234}Th, ^{7}Be, ^{137}Cs, and ^{210}Pb), and porosity. X-radiography has been completed, and radioisotope analyses will be complete by 11/1/00. Live organisms have been returned to laboratories at LSU and NRL to prepare for mesocosm experiments, scheduled for Fall 2000. Construction of a NaI-γ detector system for measuring bioturbation in microcosms has begun. In addition to the two species identified above, populations of the polychaete *Notomastus* sp. (a large head-down, deposit-feeding polychaete), and two species of deep-deposit-feeding brittlestars have been collected and identified for potential study.

RESULTS

Based on laboratory observations and X-radiographs, the burrow geometry and feeding style of *Schizocardium* and *Hemipholis* have been identified (Fig. 1). More detailed understanding of feeding and burrowing depths and rates will be possible once microcosm experiments and radionuclide measurements from cores have been completed and analyzed.

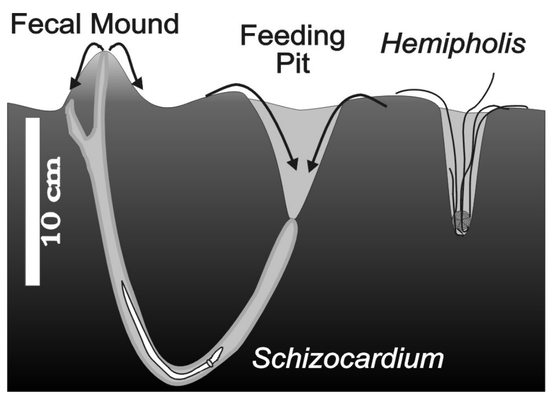

Figure 2. Typical geometry of Schizocardium and Hemipholis burrows. Schizocardium appears to ingest both consolidated sediment from walls of the feeding pit, as well as material that falls into the pit. Sediment is egested to the fecal mound as puffs of mucous-laden flocs, with no pelletization or coiled structure. Hemipholis arms are frequently extended into the water column, evidently searching for food particles, but are also seen sifting through surficial sediment. Burrows are readily visible through glass mesocosm walls. Scale is approximate.

IMPACT/APPLICATIONS

This study will provide important detailed, quantitative models of bioturbation by subtidal marine invertebrates that are based on direct observation and mechanistic modeling, rather than descriptions based on inferred organism behavior. Quantitative assessment of these processes is important because of the profound influence organism behavior can have on sediment geochemical, physical, and acoustic properties (Berner, 1982; Rhoads and Boyer, 1982; Richardson et al., 1983). Preliminary results of this work (funded by NRL and LSU) have been incorporated into diagenetic models developed by Furukawa et al. (submitted).

TRANSITIONS

Models describing burrow formation (or genesis of sediment heterogeneity) and particle mixing (including rates of change at the sediment-water interface) will have direct relevance to studies of object burial and remote sensing of the shallow seafloor.

RELATED PROJECTS

1. This project is one component of collaborative study (entitled "Quantitative Chemical Mass Transfer in Coastal Sediments During Early Diagenesis: Effects of Biological Transport, Mineralogy, and Fabric") among Drs. Sam Bentley (LSU-CSI, particle mixing and sedimentary fabric), Dawn Lavoie and Yoko Furukawa (NRL-SSC: sediment geochemistry, fabric, permeability, and numerical modeling), and Carla Koretsky (W. Mich. U., sediment geochemistry, numerical modeling). All field work and experimental planning has been undertaken in close collaboration with Lavoie and Furukawa, and results shared with Koretsky.

2. Tim Keen (NRL-SSC) and I are collaborating in a numerical/sedimentological study of event-layer emplacement and preservation in Mississippi Sound and the adjacent continental shelf, funded by NAVOCEANO, incorporating sediment-transport models, sediment radiochemistry, and sedimentary fabric. Because bioturbation is a primary mechanism for event-layer destruction in cohesive sediments, detailed understanding of regional bioturbation regimes significantly enhances my research efforts with Dr. Keen.

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PUBLICATIONS

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Furukawa, Y., Bentley, S.J., and Lavoie, D., 2000, Dynamic Bioirrigation Modeling in Experimental Benthic Mesocosms: Effects of Infauna Metabolism and Dissolved Oxygen Transport. Submitted, Journal of Marine Research.